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Review of Yunnan's hydropower development. Comparing small and large hydropower projects regarding their environmental implications and socio-economic consequences

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A R T I C L E I N F O

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A B S T R A C T

The PR China has been very fast developing its energy sector in order to sustain its impressive economic growth. China's installed hydropower capacity is not only the highest in the world; it also shows a globally unique dimension in growth and dynamic. The southwestern province of Yunnan has one of the highest hydropower potentials within China. Its development makes the province one of the key suppliers of electric energy in China, supplying the economic and energy hungry load centers of coastal China but also Southeast Asia. In a decade Yunnan will have an installed hydropower capacity that exceeds that of Canada or the United States. The province is therefore often referred to as China's forthcoming (hydro-) powerhouse or as Asia's battery.

Yunnan's rapid development is mainly based on large and prestigious hydropower projects along major rivers, often forming large reservoirs. Secondly it rests on centers of small hydropower development. They are based on small (sub-)catchments where SHP stations mostly form cascades of diversion type projects affecting entire watersheds. Both developments are creating hydroscapes. While Yunnan's large scale hydropower development is relatively well studied, there is an obvious research gap on Yunnan's small hydropower sector. But the latter has not only a huge relevance it also causes serious tangible cumulative implications.

This rapid expansion of Yunnan's hydropower sector takes place in one of the most biologically, geographically and ethnically diverse regions in China. This creates a large need for careful management in order to avoid potentially significant environmental and social conflicts. Therefore the article shows the current status of Yunnan's ambitious hydropower development program including its political frame. It critically analyses the environmental and socio-economic consequences of both large and small hydropower projects. It further describes the transboundary implications and the relevance of the power grid.

Contents

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1. Introduction

PR China's GDP growth has been the highest in the world for years. The rapidly growing economic development is inevitably accompanied with an increasing demand for energy in general and electric power in particular. China has been fast developing its energy sector in order to sustain its impressive economic growth and provide electricity for the most populated state.

The challenge of the rapidly growing energy and power sector in the 21st century is unique worldwide. A key issue within the present and future energy sector strategy is to generate and supply electrical energy for the rapidly growing economy and urban population, as well as mitigating carbon emissions. Finding a proper solution for this energy bottleneck will determine the economic, social and sustainability future of China.

In 1980, in the early years of China's economic liberalization, it had merely 66 GW of installed capacity, today it has 1139 GW globally the largest capacity (see Fig. 1). This extremely fast growth is unparalleled in the world. Presently, China adds a new installed capacity in less than two years that is comparable to the entire installed capacity of a strong West European economy like Germany or France. Despite this strong growth, China's power sector faces temporary cyclic shortages. The latest were in 2002–2005 and in 2010–2011.

With the breakup of the former Chinese Ministry of Energy in 1997 and the subsequent State Power Corporation in 2002, Chinese power generation was separated from the grid but also from the project planning. As a result of these reforms, large state owned holdings emerged in their field. These holdings control about half of the Chinese power market and are becoming increasingly active on a global scale.

China's primary energy resource is still coal. About two third of the installed capacity is thermal power (mainly coal, but also gas and petroleum); its share in the energy production output is even higher. Although China's coal use grows fast and steadily, over the last years the country closed about 77 GW of old, small or inefficient thermal power plants. Aside from the massive development of thermal power stations, China is seriously working in diversifying its power mix and reducing the ratio of carbon emissions.

These developments place regenerative energy, mainly hydropower, in a prominent role in China's present and future energy sector strategy. China has an ambitious target of meeting 15% of its primary energy demand with renewable energy by 2020. This share should be increased to 20% in 2030. In that scenario the role of hydropower in power generation is substantially greater than any other renewable energy technology.

Therefore, the present growth and dynamic of China's hydropower sector is in a dimension which is globally unique. In 2012 an immense 249 GW were generated by hydropower (see Fig. 1). In the global context China ranks first and has by far the highest installed hydropower capacity and the largest annual growth. These 249 GW are so high that it exceeds the cumulative installed capacity of the USA, Canada and Brazil, which rank directly behind China (see Fig. 2). Over the last years China added in average between 15 and 20 GW/year in new hydropower capacity [1].

Within China, the province of Yunnan, plays a key role in its future hydropower scenario. Yunnan has been implementing >90 GW of hydropower, of which currently almost half is installed. At present makes Yunnan one of the largest hydropower generating regions worldwide. Additional Yunnan has an unique geographic and geopolitical setting. It is characterized by its unique bio-, geo- and ethnic diversity as well as by its six important basins, four of which are international. These unique features have caused a special scientific interest in Yunnan's hydropower development [1–5].

We aim to analyze three major objectives. First, we study the present state of Yunnan's specific and unique hydropower development. Second, we compare social and environmental

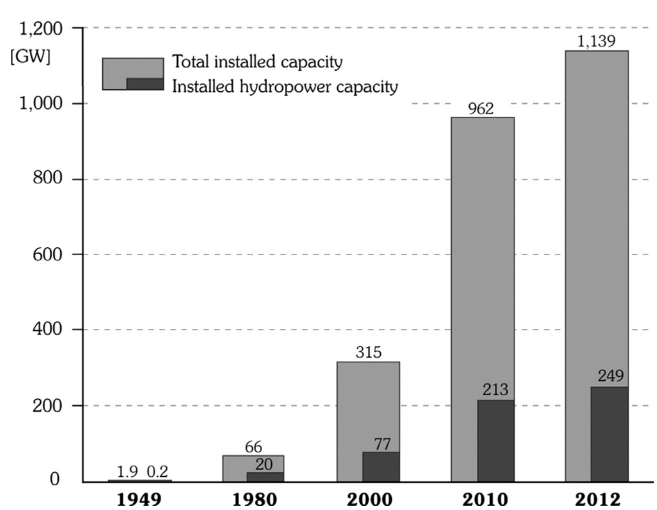

Fig. 1. Growth of China's installed power and hydropower capacity (selected years).

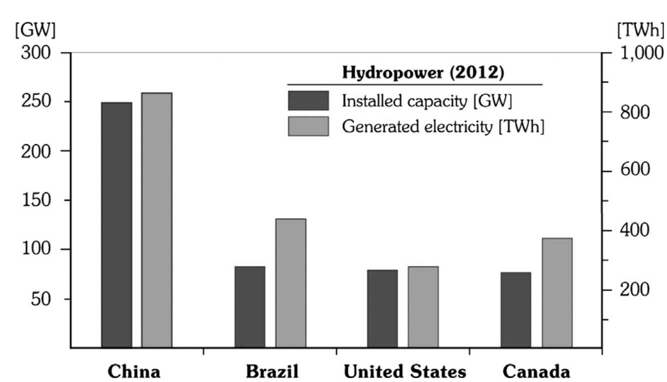

Fig. 2. Comparison of the installed capacity and generated electricity of the four leading hydropower nations in 2012.

consequences of both, small and large scale hydropower development. And third, we describe the transboundary implications and the relevance of the power grid.

2. Short characteristics of China's hydropower development

China's rise to the leading hydropower nation began relatively late; its first hydropower station was built in 1912 in Shilongba (2×240 kW), near Yunnan's provincial capital of Kunming. At the founding of the nation in 1949, PR China had only about 40 small and five large hydropower stations. This situation was very different from Europe and in particular the United States, which at that time had not only a large number but also larger hydropower stations constructed, like the Hoover Dam or the Grand Coulee Dam.

In the early industrialization of the 1950s China developed its hydropower sector quickly. Later, during the Great Leap Forward, a campaign for constructing large reservoirs began. Up to the end of last century, Chinese hydropower development was not only dependent on foreign assistance (mainly from the Soviet Union) but also due to the large capital investments required as foreign aid (e.g. the Soviet Union, but later also from international funding institutions, like Worldbank (WB), Asian Development Bank (ADB), etc.). Additionally, especially the early prestigious projects were not developed solely for power generation and were therefore multipurpose in nature. Due to the large initial capital outlays for these projects, hydropower provided often the means to pay for required irrigation and related food security, as well as for water supply or flood control.

In the mid-1980s the share of hydropower in the energy portfolio reached its peak, with about 30% in the installed capacity as well as in the energy output. Afterwards, the relative share declined to 22% in 2010, although the absolute growth is still impressive.

The situation has changed significantly, especially since the new millennia. China's growing expertise in hydropower construction, the fast growing demand on (hydro-)power generation, as well as China's rising financial strength altered the pattern of hydropower development. Today China funds not only hydropower projects mostly on its own; it is also developing many projects with the main objective of hydropower generation. Therefore, many projects have been constructed in more suitable humid and mountainous areas, where hydropower was either the sole purpose or at least the main one. In most of the recent projects irrigation plays a less crucial role and therefore flood control and improved navigation become the primary purpose besides power generation.

China has carried out intensive research and investigation on hydro resources in four large scale surveys. The last survey of 2005 indicated a gross theoretical hydropower potential of 6.083 TWh/year, which is the world's largest. Also, the more important economically feasible potential is with 1.753 TWh/year and a potential capacity of 402 GW the world's largest and twice as large as that of Russia (852 TWh/a) and Brazil (818 TWh/a), which follow next in rankings of potential economically feasible energy potential (WEC, 2010).

Due to China's vast territory and its large physiogeographic diversity, the hydraulic resources are very unevenly distributed and do not match with regional economic development on China's East and South Coast. Naturally, the hydro resources accumulate along some of the great rivers. China officially identified 14 hydropower bases (see Fig. 3). However, three of them (East Chinese Rivers, Northeast and Dongtang watershed in Hunan province) are non-priority bases, due to their relatively densely populated areas and the immense costs and social implications caused by resettlements [6]. Here the focus is more on smaller and medium sized projects.

2.1. Milestones of China's hydropower development

China's first large dam (>1000 MW) was the Liujiaxia-dam; construction started in the late 1950s but was finished only in 1974. Today China has commissioned almost 50 dams with an installed capacity of more than 1 GW. By commissioning the 1500 MW Gongboxia-Dam along the Yellow River in 2004 China was the first country to exceed 100 GW installed capacity; in late 2010 it exceeded the 200 GW limit with the completion of the Xiaowan dam along Yunnan's Lancang/Mekong river.

China's growing economic and financial strength made it increasingly less dependent on foreign sources for the financing of its dams and hydro schemes. The Worldbank (WB) or the Asian Development Bank (ADB) was involved only in certain projects. One prominent example is the 3300 MW Ertan hydropower station in Szechuan province. Built in the late 1990s, it was China's largest hydropower project before the Three Gorges Dam. Finished before the World Commission on Dams published its strategic priorities for improved decision-making, management and planning of dams, Ertan received one of the largest single project credits from the Worldbank. It was China's first hydropower plant to be built through international bidding, as well as China's first 200 m dam.

In 1994, after about 70 years of discussion, China began the construction of the Three Gorges Dam The Three Gorges Dam is the world's biggest hydropower station in terms of installed capacity (20,300 MW). The prestige project, which began first commercial operation in 2008, is the second largest in terms of electricity production.

In 2011 China announced first ideas about constructing a mega dam on the famous bend of the Yarlung Tsangpo. The potential capacity of that dam could be more than 40 GW, which is double that of the Three Gorges Dam.

Beside milestones in terms of installed capacity, China also gains world class references for other hydropower related parameters. China was the first to use 550 MW turbines in its Ertan project, and presently China is one of the few countries which uses 700 MW turbines (Three Gorges Dam). Based on Jinsha's forthcoming Wudongde and Baihetan hydropower stations, China will be the first country to get the ability to independently design and manufacture the world's largest hydropower-generating single units (1000 MW) [28]. Depending on dam design, China also hosts some of the world's highest dams (e.g. Jinping-1; Longtan or Shuibuya).

Another landmark of China's dam and reservoir construction is the dimension of dislocation. There are currently about 23 million registered relocations in China [7], and if the number of past projects is included, the figure is much higher. An estimated 1.3 million were relocated for the Three Gorges Dam alone [8].

3. Regional introduction

3.1. Hydropower potential of southwest China

By far China's largest hydropower potential is in its southwestern provinces (Yunnan, Sichuan and Tibet), or the topographical region between the Eastern Himalayas and the Hengduan mountain range. Some of the world's largest rivers (e.g. Yarlung Tsangpo/Brahmaputra, Jinsha/Yangtze, Lancang/Mekong, Nu/Salween and Irrawaddy) change their topography here (hydraulic gradient) from plateau via a long transition area, with often deep gorge topography, to that of lowland topography and landlocked alluvial plains. Combined with its wide

Fig. 3. China's hydropower development (2013): large hydropower bases (including potential of the base and mega hydropower projects > 500 MW) and small hydropower bases and major UHVDC transmission lines related to hydropower.

range of climatic settings, this region is one of the core areas around the world for hydropower development.

China's hydro bases are well suited for cascade and stage development of river basins. Considering that potential with other parameters, like submergence, related costs of relocation, construction costs of dams and transmission lines, etc. China has given priority in the early surveys to developing the Yellow River, the upper Yangtze, the Hongshui and the Wu rivers. In later surveys, as well as in the context of China's ambitious Western Development Program, the following rivers were favoured: Jinsha/upper part of Yangtze, Lancang/Mekong, Dadu, Yalong and Nu/Salween. In early 2011 China officially announced ideas of developing the Yarlung Tsangpo as one of the country's largest hydropower bases.

One challenge of hydropower development is the uneven intra- and inter-annual runoff distribution, which causes large differences between the rainy and dry seasons. This results in a large quantity of non-beneficial spillage during the rainy season and deficient generation in the dry season. In that period, hydropower must be supplemented, mainly by thermal power. To reduce this discrepancy, China invests large sums in the construction of pumped storage systems. Compared to large scale hydropower stations, the large scale pumped storage projects are mainly

located near the load centers. In 2012 China had a hydropower storage capacity of 20.3 GW, which ranks third in the world. But in an ambitious program it should almost double to 41 GW in the current FYP (2012–2017) [9].

3.2. Hydropower potential of Yunnan

In 2010 amendments to the Renewable Energy Law took effect which has an impact on Yunnan's development of renewable energy in general and hydropower in particular. Yunnan has an economic and technic feasible hydropower potential exceeding 90 GW. In early 2012 Yunnan's total installed capacity was 40,872 MW. Almost 30 GW comes from hydropower and about 10 GW is contributed by 11 large thermal power stations. Further 790 MW of grid feeding wind power and 40 MW grid-feeding PV was installed; in particular wind power grows very fast. End of the year it should rise to about 3 GW. With the completion of the proposed oil and gas pipeline from Myanmar to Kunming also gas power plants are forthcoming [2].

This rapid expansion of Yunnan's hydropower sector is occurring in one of the richest regions in bio-, geo- and ethnic diversity within China. The southwestern province of Yunnan, which is almost comparable in size to Germany, shares a long international border with Vietnam, Lao PDR and Myanmar. Yunnan's complex geography results in an outstanding geodiversity. This, combined with a diverse climate ranging from tropical to temperate, has led to a unique diversity of ecosystems, from tropical rainforests in the south to shrub and grasslands in the alpine mountainous north [10]. Yunnan is part of two of the world's major biodiversity ‘hotspots’ and several important ecoregions [11,12]. Yunnan hosts about half of China's biodiversity, and boasts the second highest species abundance index in Southeast Asia [13,14]. It has the richest diversity of higher plants in China and a high variety of fungus, algae and lichens, many of which are endemic [15]. In terms of animal diversity, Yunnan is the most notable region in the Northern Hemisphere [11]. Particularly during the past 50 years, many areas of Yunnan have witnessed changes in the state of biodiversity at an unprecedented pace and scale.

Fig. 4. Power sector of Yunnan province (2012).

Beside its rich bio- and geodiversity, Yunnan has also a remarkable ethnic and cultural diversity, which results from its long history along the networks of the Southwestern Silk Road. About 14 million people – almost one third of its population – belong to the 26 ethnic groups that are recognized as minorities, which makes Yunnan into the ethnically richest province in China [16].

Some of the world's largest rivers and their tributaries flow through Yunnan. The province has part of six major watersheds which drain into the Pacific (Jinsha/Upper Yangtze), the South Chinese Sea (Lancang/Mekong; Red River, Nanpan/Upper part of Pearl River) and the Indian Ocean (Irrawaddy and Nu/Salween). Combined with the topography (hydraulic gradient) and the climatic setting, Yunnan is one of the global core areas for hydropower development, and is therefore referred as Southeast Asia's watertower, China's (hydro)powerhouse or battery, etc.

4. Yunnan's LHP development

4.1. Present state

The rapid development of Yunnan's hydropower potential is mainly based on large projects, whereas three rivers are especially relevant (Upper Yangtze, Mekong and Salween). The proposed power stations on the main stem of these rivers are all planned as cascade systems (see Figs. 3 and 4). Most of the projects will be large ones, and often they are designed as run-off-river systems where parts of the river are e.g. diverted through large tunnels. Only a few projects are designed as huge reservoirs.

The Jinsha, flowing from the Eastern Tibetan Plateau to the lowlying Sichuan Basin with a drop of more than 2000 m alone in Yunnan, has an enormous potential to supply economically exploitable hydropower. The hydroelectric energy is very cost-effective, particularly in the lower Jinsha [17]. The operator of the Three Gorges Dam, the CTGC, is presently constructing a cascade here with four hydropower stations which have a combined capacity double that of the Three Gorges Dam. Two of the projects (Baihetan and Xiluodu) belong to the largest worldwide. Presently, China is one of the few countries which use 700 MW turbines. However, by building lower Jinsha's Wudongde and Baihetan hydropower stations, China will be the first country to have the ability to independently design and manufacture the world's largest hydropower-generating single units (1000 MW).

A second cascade is under construction in the middle reaches of the Jinsha. It was originally planned as a cascade of eight major dams, which is developed by the Jinsha Hydropower Development Corp., but the projects itself are mostly owned by different state owned companies. The 2400 MW Jin'anqiao-project is not only the first commissioned project of the cascade (in 2011), but also China's first large hydropower station primarily owned and developed by a private company, Hanergy. Other, often controversial projects on that river section are explained in the next chapter.

The Lancang or Mekong river has an altitude difference of 1780 m in Yunnan. The lower cascade currently consist six dams. It is developed by Hydrolancang, a consortium mainly owned by the Huaneng company. The 1500 MW Manwan Dam, completed in 1995, was the first dam on the Mekong and also Yunnan's first major dam. Its funding had a model character at that time because no international donors were included. Yunnan became a power exporter with the second dam (Dachaoshan; 1350 MW; commissioned in 2003). The original investment for the third dam (Jinghong; 1750 MW; commissioned in 2008), which was scheduled as China's first international hydropower joint venture (Thai), failed from the Thai-side and it is further not decided yet, if more than 1000 km transmission line to Thailand gets realized. With the fourth dam, Xiaowan (4200 MW; finished in 2010), China exceeded 200 GW installed hydropower capacity. The largest project (Nozhuadu; 5850 MW) will be completely transitioned into operation in 2014 and entirely used for electricity export. On the upper part of the Lancang/Mekong, Huaneng started in 2012 a second hydropower-cascade of another seven dams [2,3,18]. The situation about the proposed cascade of 13 dams along the Nu/Salween is explained in the next chapter.

4.2. Comparing social and environmental implications

In particular the famous and influential report by the World Commission on Dams (WCD) [19] restarted a debate about hydropolitics and the environmental and social impacts of large dams, with a focus on Asia [20–23]. China officially rejects the WCD report. However the country is not averse to international cooperation. Its domestic hydropower and dam legislation policy, which includes resettlement issues as well as Environment Impact Assessment, has been influenced by international debates and by their own characteristic domestic learning policy. Despite the official rejection, hydropower projects which are either internationally funded or requesting for CDM have to follow the rules by the World Commission on Dams.

The decision to construct larger hydropower projects or not is made on the basis of the assessment of its economic development and the related energy needs. Local rural development programs also play an important role for smaller projects. Beside these economically driven needs, environmental safeguards are relevant for both large and smaller projects as proofed in the EIA (Environmental Impact Assessment). The development of the Chinese EIA since 1979 is the result of domestic learning processes and the studies of international examples and experiences. They therefore underlie frequent adaptions and modifications.

Chinese formal EIA procedures conform to international standards. Although their implementation is also gradually based on that standards, but in certain cases it is still insufficient. In some cases the EIA was published and approved only after the hydropower project was constructed. Additionally, public disclosure of the entire EIA report is not necessary; only summaries of EIAs must be published. In order to strengthen the EIA procedure, many hydropower projects now must be reviewed and approved by either provincial or central authorities. Despite the still often weak EIA-implementation, a few cases spurred the debate on hydropower projects in Yunnan in particular during the previous 11th FYP.

- In June 2009 China's Ministry of Environment Protection halted two large hydropower projects along the Jinsha river (Upper Yangtze). The move was considered the severest punishment in the country's environmental appraisal history as it involved two large state-owned conglomerates Huadian (Ludila-dam; 2200 MW) and Huaneng (Longkaikou-dam; 1700 MW). But in November 2010 the influential National Development and Reform Commission (NDRC) gave official clearance after reducing the environmental influence. The 2400 MW Jin'AnQiao project on the same river, which is relevant for the transmission to Guangdong received formal EIA-approval in 2010, shortly before construction was finished.
- The development of the Nu river cascade is widely and often controversy discussed [7,24–27]. It is halted since 2004 and subject to environmental investigation. The Nu or Salween river is international and its development is therefore a central governmental responsibility. Although first ideas about the Nu-projects came up in the 1970s, the NDRC adopted a plan for a cascade based on 13 dams with a combined capacity of 23 GW in 1999. The proposed developer, state owned Huadian Corp., tried together with the provincial government of Yunnan

to rush China's State Council into approving the projects before the new EIA law could come into effect in 2003. China's former SEPA and a Beijing-based NGO began to show their strong differing opinions to the project. This resulted in an unique situation for China, establishing a link between researchers, NGO activists and politicians. Huadian was forced to conduct an EIA and submit it to the SEPA. Finally, then Prime Minister Wen Jiabao halted the project since 2004 due to an insufficient EIA. In the meantime, the EIA report had been completed and approved; but due to the sensitivity of the project hardly any information leaked out. The current 12 FYP exclusively mentions five projects for construction. Intensive preparations are being undertaken at these sites, including the potential locations for the two largest projects at Maji and Songta. While Guodian is doing the preparatory work, Huaneng is responsible for the later proper dam development. Before dam construction an appropriate infrastructure has to be constructed. No project is presently under construction, although five projects are exclusively mentioned in the current 12 FYP.

- Beside the Nu-cascade China's most controversial hydropower project was the 2800 MW upper Hutiaoxiao dam. The proposed dam, with a height of 276 m, would officially relocate more than 100,000 people, mostly minorities. The dam location was in the Tiger Leaping Gorge on the Jinsha (Upper Yangtze), one of the world's most spectacular canyons. The proposed dam was also aimed at diverting water from the Jinsha to the provincial capital, which lacks drinking water. The plan was opposed by Chinese NGOs and caused an unexpected public outcry, which was supported by the Chinese Media and received international attention. Therefore the plan has been shelved in 2004.

These examples of environmental and socio-economic issues present a mixed picture about China's hydropower decision making process for large projects. On the one side the process is still secretive, top-down oriented and authoritarian, but on the other side EIAs can act as a powerful tool. Further democratic procedures get introduced and, in certain cases, individuals and civil society organizations can organize effective protests and even stop controversial projects.

Beside environmental issues, socio-economic consequences are also a key challenge to Yunnan's hydropower development. There are currently about 22 million registered relocatees in China [28], and according to the WCD-report between 1949 and 1999 about 12 million people were displaced due to reservoir construction. Millions more were displaced due to the construction of the Three Gorges Dam and other large hydropower schemes. In many cases, people were moved to other areas and provinces, which raised assimilation problems and resulted in conflicts with the resident population [8]. Growing problems related to resettlement were solved by passing a number of new laws and regulations. Now the implementation of newly approved resettlement plans are the responsibility of county and sometimes even provincial governments, while the monitoring and evaluation are carried out by external agencies.

The already immense and steadily growing costs of resettlements are a major reason for the lack of new hydropower projects in more densely populated areas of China, mainly in the East and South. Studies by the authors of recent hydropower related relocation projects in Yunnan indicate that they were done according to the Chinese rules. Relocated villagers (including village committees) do not complain about the relocation itself, but about the intransparent decision making and the lack of participation in relevant decision making and co-determination [2]. They further indicate that physiogeographic parameters of relocation sites are important indicators of economic wellbeing for relocatees [29].

Due to the environmental and social constraints of large dams, China favoured during the last Five Year Plan (11th FYP; 2006–2011) more smaller and medium hydropower projects. In the current FYP it prioritizes again large dams.

4.3. Transmission lines

The development of Yunnan's hydro resources makes the province one of the key suppliers of electric energy in PR China, supplying the economic and energy hungry centers of eastern and southern China and less relevant also neighboring southeast Asia. To get hydropower generated electric energy to these far away load centers, a robust and efficient high-voltage transmission system is required, which is only available at high economic costs. Yunnan follows a two way export strategy: first it is a more seasonal and flexible export within the five provincial grids of CSPG. It is mainly fed by small and large hydropower stations as well as by thermal power plants. The second pillar is a long distant bulk transmission using UHVDC technology (ultra high voltage direct current). In Yunnan it is based on singular large HP projects along Jinsha and Mekong.

The latter technique, although far more expensive than the common high voltage transmission, has two major advantages: it reduces carbon emissions and has only minor losses even over long distances. The world's first 800 kV UHVDC project (pole 1) began operation in late 2009. The project reduces the transmission losses to a mere 3.5%. Compared with the present upper standard of 500 kV DC, the line losses drop by approximately 60% at the same power; for 660 kV, the loss reduction is 43% [30]. China is the only country building so many powerful long distant bulk transmission lines. Currently alone 11 such lines are either existing or under construction from southwest Chinese hydropower stations.

4.4. Transboundary implications of Yunnan's LHP projects

Over the last decades Chinese dam builders have accumulated a vast expertise and knowledge base in hydropower construction. Since the turn of the millennia, China's growing financial reserves and economic strength have made it very successful in realizing many projects, both locally as well as globally. This is fostered by a perception of hydropower as a strategic venture. Chinese dam builders and financiers accelerated dam construction in different parts of the world. Especially relevant are the neighboring countries, in particular Myanmar [31,32]. Many Chinese dam builders are currently undertaking several initiatives in order to be perceived as become good corporate citizens rather than rogue players on the global market.

Presently, about 40 foreign hydropower stations have been completed by China and more than 200 are under construction or planned. Chinese hydropower activities are global, but the majority of the projects are in Southeast Asia and Africa, where China has fostered strategic regional and bilateral ties. The major actors and drivers of Chinese overseas hydropower ambitions are the six major state owned power suppliers, but also private companies are involved, such as Sinohydro, China Southern Power Grid, various Chinese Banks (mainly China Exim Bank) and also Yunnan based companies.

For Chinese hydropower activities abroad, Yunnan plays a crucial role due to its geopolitical position close to Southeast Asia. A number of projects in Myanmar are already now of direct relevance to Yunnan, because they feed 85% of the generated electricity into the Chinese grid (CSPG). Both existing dams and those under construction are developed by a Big Five company on a 40 year BOT basis. The largest project is that of China Power Invest (CPI), which develops the upper Irrawaddy cascade (13.4 GW). It includes the controversial currently halted Myitsone

dam which caused diplomatic irritations between the two countries. Other important forthcoming projects are that on the river Shweli as well as the proposed dams on the upper Salween. But also dams that were constructed in areas which are controlled by various local groups (Shan, Kachin, etc.), caused political tensions between the two countries. These groups partly blame Chinese companies for doing other activities than hydropower construction and even attacked a hydropower construction site in 2009.

Beside Chinese hydropower ambitions abroad, China's local hydropower development affects its neighbors downstream. First, a province like Yunnan, sends electricity to energy hungry North Vietnam and, in the future, also to Thailand. Second, most of Yunnan's watersheds cross national boundaries. The hydropower development here affects downstream countries, like that on the Mekong.

China is part of the GMS initiative with Yunnan and Guangxi, but it is not part of the Mekong River Commission; possible consequences of hydropower development on the Mekong for its upper and lower riparian states are intensively discussed [22,33–35]. Particularly the serious drought which affected in 2010 the region produced controversial discussions and disputes between upstream Yunnan (or China) and downstream states about the causes and effects of damming up Yunnan's Lancang/Mekong River [36]. Beside these discussions, the downstream Mekong states also plan the construction of 13 additional major dams in the lower part of the Mekong. The developers of those projects are mainly from China and from Thailand, but also from Vietnam and France. For the binational watershed of the Nu/Salween, it is striking that China has thus far stopped damming up its own part of the river. However, China is also very active in the hydropower development along the Salween in Myanmar together with Thailand.

The forthcoming conflict on the Yarlung Tsangpo where China and India are directly involved is much more serious. The river, which is also called Brahmaputra in India and Siang in Arunachal Pradesh has been for long, beside the Nu, the only undammed major river in China. In early 2011 China officially started construction of the first four dams along the Yarlung Tsangpo and it announced ideas to construct the world's largest dam (> 40 GW) on the famous bend of the Yarlung Tsangpo. It caused a political outcry in downstream India and the country revived its idea of constructing a 10 GW project on the upper Siang. This would be India's largest hydro project so far. New Delhi is supporting state-owned power companies (namely NTPC and NHPC) and the Arunachal government to speed up their own projects on the river. The background is the doctrine of prior appropriation in that contested border region, which indicates that the priority right for the river falls to its first user.

5. China's and Yunnan's SHP development

5.1. China's SHP development

China's impressive status of SHP development is closely related to programs for rural electrification. China presents a good example of a developing country that has successfully embarked on rural electrification and energy projects over the last decades and achieved almost 100% electrification [37].

China's major backbone for rural electrification has long been SHP, which supplies more than 97% of China's renewable electricity. About 653 rural counties have achieved their preliminary electrification from SHPs. The installed SHP capacity has increased from 6.93 GW in 1980 to currently 62 GW. China accounts for half of the world's SHP capacity. In 2013 China published its first national census on water which accounts 98,002 reservoirs and 46,758 HP stations. 98.6% of the hydropower stations are of small size [38].

But China's impressive figure is also based on inconsistency of the definition of SHP and related data. Presently, China defines SHP up to a capacity of 50 MW. In the 1950s, only stations below 0.5 MW were considered SHP. Later, the size increased to 3 MW, 12 MW, 25 MW and now to 50 MW. There is no international consensus on the definition of small hydropower. The generally accepted norm is 10 MW in Europe, while in the United States or India it is a capacity of up to 25 MW. China's SHP development is mainly based on a decentralized system approach, especially on a local level with a county as the basic unit. The successful pilot project (7th FYP; 1986–90) to electrify 109 counties resulted in the main goal of rural electrification through SHP exploitation. Yunnan's Dehong prefecture was the second rural region in China which was totally electrified and this exclusively by hydropower. The concept of rural electrification is based on the idea 'walking with two legs'. The first leg is 'self-consumption,' which implies that there should be a county based SHP market. The second leg, which became more relevant in recent time, is a combination of SHP cascades and larger hydropower projects to create a hydropower hub that feeds into the larger regional and finally the national electrical grid.

While former FYPs mainly focused on a rural, county based electrification, the last 11th FYP changed the focus to include the development of county based SHP bases. China presently develops 15 of those small hydropower bases (cp. Fig. 3). Each of them has an installed capacity of not less than 1000 MW. Not only the state, but also provinces establish such hydropower bases. Their development is mainly driven by private entrepreneurs as well as local governments and local power grids. Despite its strong growth, the development is still far below its estimated potential of 128 GW capacity and 450 TWh/y average generation [6].

The above mentioned features resulted in SHP development with distinct Chinese characteristics. This development is promoted by their categorization up to 50 MW, so that SHPs can also serve as multipurpose projects which have further functions, such as flood control, irrigation or rural/urban water supply. Therefore, SHPs can be divided into three types: run-of-river SHP, adjustable SHP as well as irrigation SHP. China's SHP sector has become regionally a major grid feeder. China's SHP resources are unevenly distributed; over 50% of China's total SHP capacity is located in SW China (Yunnan, Szechuan and Tibet). On the other side the most developed SHP regions are mainly the provinces along the southern and eastern coast (Guangdong, Fujian, Sichuan, Hunan, etc.).

China's SHP sector continues to grow rapidly. This growth is caused by different factors, such as (i) a huge rural market/electricity demand; (ii) the importance of the global CDM market due to SHP's lacking emissions and (iii) its mature technology as well as better grid feeding options. Nevertheless, the installed capacity ratio between SHP and fossil generation is shrinking. Besides its impressive success, the SHP sector also faces some challenges and problems. It is subject to seasonal influence (unstable electricity output) as well as rising costs for new SHPs and tariff pricing constraints, which do not reflect the external benefits [39].

5.2. Present state of Yunnan's SHP development

Due to its mountainous topography, Yunnan has one of the largest installed SHP capacities in China, but its potential is only to 59% exploited. In 2005, 19% of Yunnan's installed hydropower capacity was produced by SHPs [40], in 2010 grew the figure to 65% which corresponds to an installed SHP capacity of 16.7 GW [41]. The relative figure will decrease because since 2010 some large HP stations along the Mekong and Jinsha started commissioning.

There were three key events which advanced massive SHP development in Yunnan. First, the breakup of China's state power monopoly in 2002 allowed also private investors to enter Yunnan's hydropower market. SHPs are more attractive for private investors due to the high initial investments of hydropower plants. Due to the financial constraints in one of the poor provinces, most of the investors are not local, but rather from coastal provinces (e.g. Zhejiang, Fujian, Guangdong, Shanghai, etc.). Secondly, the completion of the West-to-East-Transmission scheme in 2005 resulted in attractive export conditions for Yunnan's hydropower generated electricity. The SHP sector also took advantage of these conditions and became an integral part of Yunnan's power transfer. A third event helped Yunnan's SHP development. The global CDM market made many SHP projects financially attractive. But information leaked slowly to remote areas in Yunnan, so that the CDM market started relatively late. Today the provinces of Yunnan and Szechuan are globally leading in applied and registered CDM projects. Alone Yunnan currently has hydropower projects in the CDM pipeline, which are more than countries like India (303) and Vietnam (223) which follow globally second and third to China. 88% of Yunnan's hydropower projects in the CDM pipeline are of small size [42,43].

These three key events resulted not only in a massive SHP development in Yunnan, but gradually facilitated the transformation from SHP as a primary hydraulic energy resource to an electricity commodity. Also, all areas of Yunnan benefit from SHP development, four regions have been gradually developing into an SHP hub, having a cumulative SHP capacity exceeding one GW. An SHP hub is a cluster of SHPs within a small area (mostly a county) with a cumulative installed capacity of about 1000 MW. While Yingjiang county of Dehong already reached that stage, other regions of Yunnan are gradually developing that stage. Nujiang and Lincang prefecture as well as the Yuanjiang region are following.

Beside the controversial large projects on the main stem of the Nu river, we identified 88 SHP projects in the Nu prefecture. But due to the special topography the situation differs compared to the other SHP bases. Due to the small tributaries only between one and three SHP stations forming one cascade. The major difference is the lack of an adequate transmission line which is able to transmit the generated electricity, mainly in the rainy season.

5.3. Status quo, environmental and socio-economic implications of the Yingjiang base

Yunnan's major SHP hub is the Yingjiang county in the Dehong prefecture, which was studied in greater detail by the authors [43–45]. It is part of the Chinese Irrawaddy catchment. Dehong is a small prefecture (11,526 km^2) which shares a long border with Myanmar. It is characterized by a sharp decline of the Gaoligongshan mountain range fan, which results in an alternation of densely populated basins and steep mountain ranges of up to 3200 m NN. The vegetation is partly tropical and especially the Tongbiguan Nature Reserve combines a very high biodiversity due to the mix of Indian, Chinese and southeast Asian flora.

The remote region first received stable electricity for the prefectural headquarter Mangshe in 1970. It was generated by an SHP station (4.3 MW), otherwise a few hundred decentralized pico HP provided temporary electricity for local communities.

Until the turn of the new millennium a few more SHPs were constructed also a first reservoir (63 MW) and most of the decentralized pico stations closed. During that time gradually a local power grid evolved. Dehong became the second rural prefecture of China which was entirely electrified and this exclusively by hydropower. In 2002, the year of the crucial reform of China's power sector, the region had merely 254 MW of installed hydropower, generated in 15 small and one larger HP station. Only one decade later the capacity skyrocked to 3720 MW, generated in 122 small and 10 larger HP stations. The large number of mostly diversion type SHP cascades create in combination with larger projects a hydropower hub that primarily feeds the national electrical grid (CSPG). About 2.3 GW of the capacity is used for exported at a cheap rate to distant Guangdong, China's leading export manufacturing region. Most of the region's hydropower stations belong to private companies. The main drivers for that rapid hydropower development are the local government as well as the former local electricity company, which is now incorporated into CSPG. Another characteristic of Dehong's power sector is the direct import of electricity two hydropower stations in adjacent Myanmar (0.84 GW). 85% of their generated electricity directly feeds into CSPG, in future more than 3 GW will be imported.

The core region of Dehong's hydropower development is the Yingjiang base, named after the correspondent county. This remote region is mainly inhabited by ethnic minorities and drained by three smaller transnational Irrawaddy tributaries. Both small and large projects cumulative generate each between 1200 and 1300 MW which makes them to one of the largest small hydropower bases of China.

The main approach of the regional SHP development is constructing SHPs as cascades. This should be illustrated using the example on the Chinese side of the transnational Namtarbet catchment (Nantaibaijiang). It has a size of about 25 × 40 km. The first SHP was commissioned in 1998, today exist 30 SHP stations. They generate 573 MW exclusively by small hydropower. According to European SHP criteria ($<$ 10 MW) only 32.2 MW would be generated in six SHP stations. The investors came mostly from Eastern China, most of them own few projects. Five SHP projects are CER credited by the Kyoto Protocol's Clean Development Mechanism (CDM), another 11 SHP are within the CDM pipeline.

21 of the 30 SHPs form one large cluster; which means that one SHP is directly merging with the following downstream one. Alone in that SHP cluster exists continuously no natural water flow over a distance of 72 km. It affects five continuous subcatchments with five different rivers plus other creeks. In the small Namtarbet catchment more than 90 km of rivers are totally dried up and dewatered during the dry season due to river diversions. Major parts of that section are border rivers to Myanmar.

The concentration of SHP bases within a small area in a peripheral and poor region of China causes various socio-economic implications. First, it results in road construction and therefore better infrastructure, but indirectly also for further resource utilization, like mining, etc. The better road access also causes a changing land use pattern in a region with relatively good forest conditions and high biodiversity. New land uses include commercial afforestation, cultivation of cash crops, etc. Third, it results for many households in more employment and job diversity and hence better living conditions.

Due to the fact that most of the SHPs are constructed as a cascade, the highly dynamic SHP development also causes direct and indirect cumulative environmental consequences. The main challenges are drying up of river sections, where the water is diverted and no minimal flow discharge is enforced. It causes blank shoal, particularly during the dry season. Another failure in that context is ensuring a riparian distance between the smaller cascade hydro projects. Both problems are caused by ineffective controlling mechanisms.

6. Conclusion and policy suggestions

China is characterized by the world's fastest growing hydropower development. Over the past decades China gained engineering and technical expertise which made it the world's most advanced hydropower market. Additionally, China is economically strong enough that

it can realize many large and expensive hydro projects without foreign aid. Since the new millennium, China's expertise and financial strength is also globally seen. It is constructing and funding a fast growing number of hydro projects worldwide.

This is underpinned by the development concept of Yunnan province. Currently it is still one of the economically undeveloped provinces but in future it will be the hydro battery of China. Then Yunnan alone will have an installed hydropower capacity which exceeds that of Canada or the United States. Yunnan's challenges of a rapid hydropower development are intensified by the fact, that four of its six large river basins are transnational. This effects both large and small scale hydropower development. Furthermore Yunnan as well as China have serious interest to develop hydropower resources in neighboring countries, mainly in Myanmar. It should support China's electricity demand. Hydropower generation is essential for sustaining China's economic growth and therefore large hydro projects are central parts of regional development initiatives in particular in southwest China. Due to the fact that they are far away from the economic load centers China combines the large scale hydropower development with the globally most advanced grid and transmission systems (UHVDC).

The main driver for China's hydropower development is the government, both on the central as well on the provincial/local level. The other major drivers are the state-owned power generation, transmission and design companies. Private companies have thus far played only a minor role for large projects. For smaller projects the situation is different. Although China is currently constructing most of the world's largest dams, it had temporary slowed down the path of large hydro projects. The 2010 approval or granted permission to continue three controversial projects in Yunnan was considered as a symbol for restarting large projects in China during the present FYP. In order to achieve its target of 15% of non-fossil fuels in primary energy consumption by 2020, China's current FYP has again a focus on large hydropower projects with a target of 380 GW hydropower capacity by 2020.

The situation in the SHP sector is quite different. Over more than two decades China has been very successfully pushing the development of small hydropower. This has been taken place county-based, primarily as part of rural electrification. Its major objective is to guarantee stable power supply for county-run and township enterprises as well as for rural households. More recently and depending on grid situation China started to develop SHP bases, which mainly support the national power demand. The main drivers for SHP development are local/regional authorities and private entrepreneurs, which also benefit from the global CDM market. SHP development has been played an increasingly important role in the socio-economic development of rural China. It is no longer merely a technology or a method to solve China's rural energy problems. It has become a new industry that plays a significant role in China's social, economic, and environmental development. Contrary the approach of SHP cascade development causes serious direct and indirect consequences if not managed carefully.

With focus on medium to large projects, China follows in its hydropower policy a classical authoritarian top-down approach, while it prefers a mixture of approaches in its SHP development. China's decision making is logically based on domestic laws, which have gradually adopted international norms. Despite this progress, the environmental implications and, to some extent the social consequences of hydropower decision making are still not transparent enough. Often the procedure is only formally adopted and this explicitly includes CDM projects. The effected local population generally argues that they have to agree to the scheduled SHP development and cannot oppose it. They also mention that they receive the officially guaranteed compensations, but they are not allowed in options of decision making about those compensating measures.

SHP projects are generally considered a priori as an environmentally sound renewable energy with almost neglible ecological consequences. What might be justified for an individual project is different for the large scale cascades as mainly developed in the region. In particular the large number of diversion type projects causes long stretches of totally dewatered sections and this has serious tangible cumulative impacts in the entire watershed. Our results indicate that the region's SHP development is fostered by weak environmental and institutional control. It shows that a local decision making process often neglects the integration of superior social and environmental norms in the planning and implementation of a SHP infrastructure. The consequences of a relatively unregulated SHP development are fostered in peripheral and smaller transnational watersheds.

Only in recent time studies came up comparing the salience and magnitude of small and large hydropower impacts in Yunnan. In particular IDAM is a new tool to evaluate the relative costs and benefits of hydropower construction based on multi-objective planning techniques [46–48]. Although presently methodically not mature, it provides a platform which allows decision-makers to evaluate alternatives and to articulate priorities associated with a dam/hydropower development, making the decision making process about dams more informed and more transparent. But first results indicate that cumulative biophysical impacts of small hydropower exceed those of large hydropower [49] which is also supported by [45].

We further criticize that there is often no serious assessment for developing a holistic concept of the entire watershed including all tributaries. This concept should go far beyond hydropower development and create an innovative management model, which considers water, environment, livelihood, food security, etc. and therefore enhances public participation and transparency as well as the financial benefits for the people in those watersheds. This is underpinned by the fact that most of the regions' watersheds are transboundary rivers. Therefore, there should be a shift from an administratively focused or sovereign state focused watershed development to an integrated transboundary watershed approach which recognizes the political sensitivities of the whole region. We finally recommend the water-energy-food-nexus as a profound perspective to develop and to monitor Yunnan's hydropower development.

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